

ADDRESSING ALGAE PROLIFERATION IN CANAL 900 OF THE LITANI RIVER BASIN IN LEBANON



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LIST OF ABBREVIATIONS

AUB	American University of Beirut
AWT	Advanced wastewater treatment
BOD	Biological Oxygen Demand
BMP	Best Management Practices
COD	Chemical Oxygen Demand
CuSO ₄	Copper sulfate
DO	Dissolved Oxygen
FC	Fecal Coliform
MSL	Mean Sea Level
N	Nitrogen
NH ₃	Ammonia
NO ₃	Nitrate
P	Phosphorous
PO ₄ ⁻³	Phosphate
TC	Total Coliform
TDS	Total Dissolved Solids
USD	United States Dollars

EXECUTIVE SUMMARY

This report describes the causes, effects, and control measures for eutrophication in general, assesses the extent of algae proliferation in Canal 900 of the South Bekaa irrigation scheme and proposes short-, medium-, and long-term remedial measures.

Eutrophication is defined as an increase in the level of nutrients in natural waters, particularly nitrogen and phosphorous, leading to accelerated algal growth and plant production. Eutrophication is essentially a natural process, but it is often exacerbated through anthropogenic causes. The main causes of eutrophication are:

- High loads of nitrogen, phosphorous, silt, organic matter, and other nutrients entering the watercourse due to land clearing, agricultural runoff, domestic wastewater, and atmospheric deposition;
- High levels of light, high temperature, low turbidity, and long watercourse retention times; and
- Watercourse control measures, such as dams, weirs, and abstraction canals.

Table A summarizes the direct and indirect impacts of eutrophication and Table B summarizes three treatment techniques.

Table A. Impacts of eutrophication

Direct Impacts	Indirect Impacts
<ul style="list-style-type: none"> ▪ Increase in production and biomass of phytoplankton, attached algae, and macrophytes ▪ Production of toxins by certain algae 	<ul style="list-style-type: none"> ▪ Shift in habitat characteristics ▪ Replacement of desirable fish with less desirable species ▪ Increased operating expenses for public water supply ▪ Taste and odor changes to drinking water ▪ Deoxygenation of water, especially after collapse of algal blooms ▪ Death of fish ▪ Infilling and clogging of irrigation canals ▪ Loss of recreational use of water ▪ Impediments to navigation ▪ Economic losses

Table B. Treatment techniques for controlling eutrophication

Approach	Technique
<ul style="list-style-type: none"> ▪ Control of external nutrient sources 	<ul style="list-style-type: none"> ▪ Nutrient diversion (intercepting lines) ▪ Advanced wastewater treatment ▪ Good agricultural practices and land use
<ul style="list-style-type: none"> ▪ In-situ nutrient control 	<ul style="list-style-type: none"> ▪ Hypolimnetic withdrawal ▪ Dilution and flushing ▪ Phosphorous inactivation ▪ Sediment oxidation ▪ Hypolimnetic aeration ▪ Sediment removal (dredging)
<ul style="list-style-type: none"> ▪ In-situ control of algae 	<ul style="list-style-type: none"> ▪ Mechanical removal of algae ▪ Application of copper sulfate ▪ Application of barley straw ▪ Flow management

A technical team conducted field surveys to assess algae proliferation in Canal 900. The canal withdraws water from Lake Qaraoun in Lebanon's Litani River Basin for a 1,750 hectare irrigation scheme in the southern part of the Bekaa Valley. The canal is 14 kilometers long, extending from the Qaraoun Dam to a closed end near the village of Kamed El Laouz. The canal has a gentle slope (0.2 percent) and a water depth of 1-2.1 meters. Water is moved via three pumping stations along the canal, distributing water to the villages of Qaraoun, Joub Jannine, and Kamed El Laouz (Figure A).

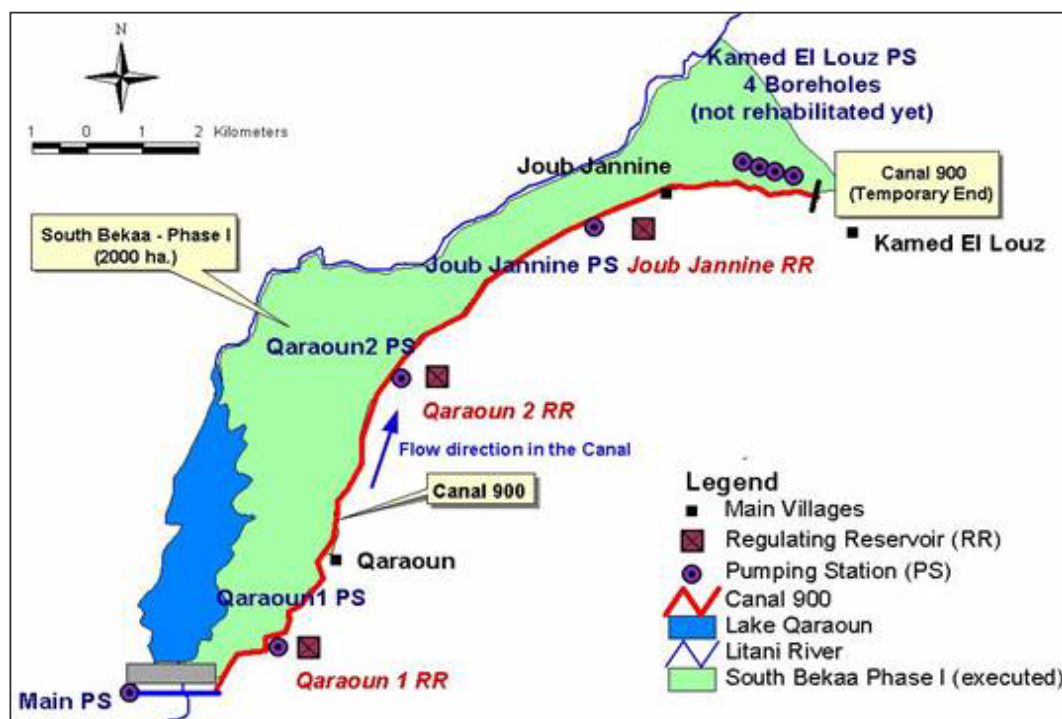


Figure A. Overview map of Canal 900

The team collected and analyzed water samples from Lake Qaraoun and the canal and analyzed them for physical, chemical, and microbiological indicators of eutrophication and pollution. The lake has mean concentrations of phosphorous of 810 mg/m^3 , eight times higher than the amount generally termed "hypereutrophic," and nitrogen levels of $5,000 \text{ mg/m}^3$, also characteristic of a hypereutrophic lake (Table C). Despite these high nutrient levels, the depth of the lake and aeration restrain algal bloom.

Table C. Characterization of the trophic status of the lake and canal

Parameter	Measured levels				Trophic status	
	Lake Qaraoun		Canal 900		Lake Qaraoun	Canal 900
	Mean	Range	Mean	Range		
Total phosphorous (mg/m ³)	810	570-1,170	379	50-940	Hypereutrophic (> 100)	Hypereutrophic (> 100)
Total nitrogen (mg/m ³)	5,000	< 5,000 – 9,000 ¹	5,200	< 5,000 – 12,000	Hypereutrophic > 5,000	Hypereutrophic > 5,000
Secchi disc transparency (m)	4.1	3.5-4.5	NA	NA	Mesotrophic (3-6)	NA
Oxygen (% saturation)	36.9	15-59	55.3	15-90	Eutrophic (0-40)	Mesotrophic (40-89)

On the other hand, when the high nutrient loads are introduced to the canal, with its low water velocity (due to its gentle slope) and improper flushing (due to its closed terminal end), algal proliferation becomes rampant. Phosphorous and nitrogen are both at hypereutrophic levels (379 mg/m³ and 5,200 mg/m³, respectively). Phosphorous levels vary along the length of the canal due to higher consumption rates by growing algae or due to external inputs from adjacent agricultural lands.

The three methods for controlling eutrophication and algae proliferation in Canal 900 are:

- The reduction of external nutrient loading into the Litani River and Lake Qaraoun,
- Treatment of the water and sediment in Lake Qaraoun to reduce existing nutrient concentrations; and
- Direct inhibition of algal growth in Canal 900.

Table D outlines the techniques used with each method and summarizes their advantages and limitations. The report concludes that in terms of cost and short-term efficacy, the application of barley straw directly to the canal is the best option. Following this, resource managers should promote better agricultural practices to minimize runoff of nutrients and consider chemical inactivation of phosphorous present in Lake Qaraoun. Another option worth considering is improving flow management and recirculation in the canal to prevent stagnation. The least favorable technique is dilution and flushing of the lake due to the scarcity of high-quality (that is, low-nutrient) water.

Table D. Methods for controlling eutrophication

Method	Remarks
1) Control of external nutrient sources	<ul style="list-style-type: none"> ▪ Long-term solution addressing the problem at its source
Nutrient diversion (intercepting lines)	<ul style="list-style-type: none"> ▪ Limited by absence of wastewater treatment plants ▪ Diverts pollutants to other locations within the watershed ▪ High capital cost
Advanced wastewater treatment	<ul style="list-style-type: none"> ▪ Limited by absence of wastewater treatment plants ▪ High capital cost
Good agricultural practices and land use	<ul style="list-style-type: none"> ▪ Requires training for farmers and local stakeholders ▪ Requires legislative enactment and enforcement
2) In-situ nutrient control	<ul style="list-style-type: none"> ▪ Essential if nutrient concentrations in the lake are high ▪ Does not control the source of nutrient loading
Hypolimnetic withdrawal	<ul style="list-style-type: none"> ▪ Requires advanced technical skills ▪ High capital and operation costs
Dilution and flushing	<ul style="list-style-type: none"> ▪ Requires large quantities of low-nutrient water ▪ High capital and operation costs
Phosphorous inactivation	<ul style="list-style-type: none"> ▪ Requires advanced technical skills
Sediment oxidation	<ul style="list-style-type: none"> ▪ Requires advanced technical skills
Hypolimnetic aeration	<ul style="list-style-type: none"> ▪ High capital and operation costs
Sediment removal (dredging)	<ul style="list-style-type: none"> ▪ Requires advanced technical skills
3) In-situ control of algae	<ul style="list-style-type: none"> ▪ Directly controls algal proliferation ▪ Temporary measure that does not reduce nutrient levels
Mechanical removal	<ul style="list-style-type: none"> ▪ Relatively low capital and operation costs ▪ Limited effectiveness at removal of algae ▪ Current method in use
Copper sulfate	<ul style="list-style-type: none"> ▪ Negative environmental impacts (sediment contamination)
Barley straw	<ul style="list-style-type: none"> ▪ Easy to apply by farmers ▪ No adverse effects if oxygenation is ensured
Flow management	<ul style="list-style-type: none"> ▪ Does not require advanced technical skills

1. CAUSES, EFFECTS, AND CONTROL OF EUTROPHICATION

Canal 900 extracts water from Lake Qaraoun, part of the Litani River basin, for the South Bekaa irrigation scheme. The canal suffers from eutrophication and algae proliferation, with consequent impacts on the irrigation scheme. The Litani River Authority has noted the following problems in particular.

- Algae is limiting water flow in the canal.
- Farmers report that drip irrigation systems are not functioning properly.
- Residents of neighboring villages are complaining of foul odors and insects.

Based on primary data, secondary sources, and academic literature, this report describes the causes, effects, and control measures for eutrophication, assesses the extent of the problem in Canal 900, and proposes potential short-, medium-, and long-term remedial measures.

Lake and canal management largely centers on “trophic status”, a concept describing the relationship between the nutrient state and the growth of organic matter in the water body (FAO, 1996). Eutrophication, literally meaning over-nourishment, is the state in which biotic growth (for example, in the form of algae) increases more rapidly than in normal conditions, leading to a reduced ability of organisms to respond to nutrient levels and the simplification of biotic communities (Wetzel, 2001). Increased organic matter can in turn lead to a loss of water volume and a depletion in dissolved oxygen. In addition, eutrophic lakes and canals are characterized by algal “blooms” (often dominated by mono-specific populations of blue-green algae), macrophytes, green/brown coloration, shallowness, limited water circulation and exchange, lack of stratification, re-suspension of sediments, and long retention times (Cooke *et al.*, 1993; Biro, 1995). Eutrophication is of greater significance where water quality is important, for example, in water supply and irrigation systems (Gophen, 1995).

1.1 Causes and Effects

Eutrophication is essentially a natural process that is exacerbated by anthropogenic processes; high-flowing rivers rarely experience outbreaks of algal bloom (LWA, 2002). The main causes of eutrophication are:

- High loads of nitrogen, phosphorous, silt, organic matter, and other nutrients typically resulting from land clearing, agricultural runoff, domestic wastewater, and atmospheric deposition;
- High levels of light, high temperature, low turbidity, and long watercourse retention times; and
- Anthropogenic control of watercourses, especially dams, weirs, and abstraction canals (Gophen, 1995; Chapman, 1996).

Figure 1 shows the biological cycle leading to eutrophication. Plant nutrients enter water bodies from point and non-point sources, and then are either recycled within the water or released from the sediments when the lower water layers become anoxic¹ (LWA, 2002). Algal production, moreover, only enhances the anoxic state of the water (Gophen, 1995).

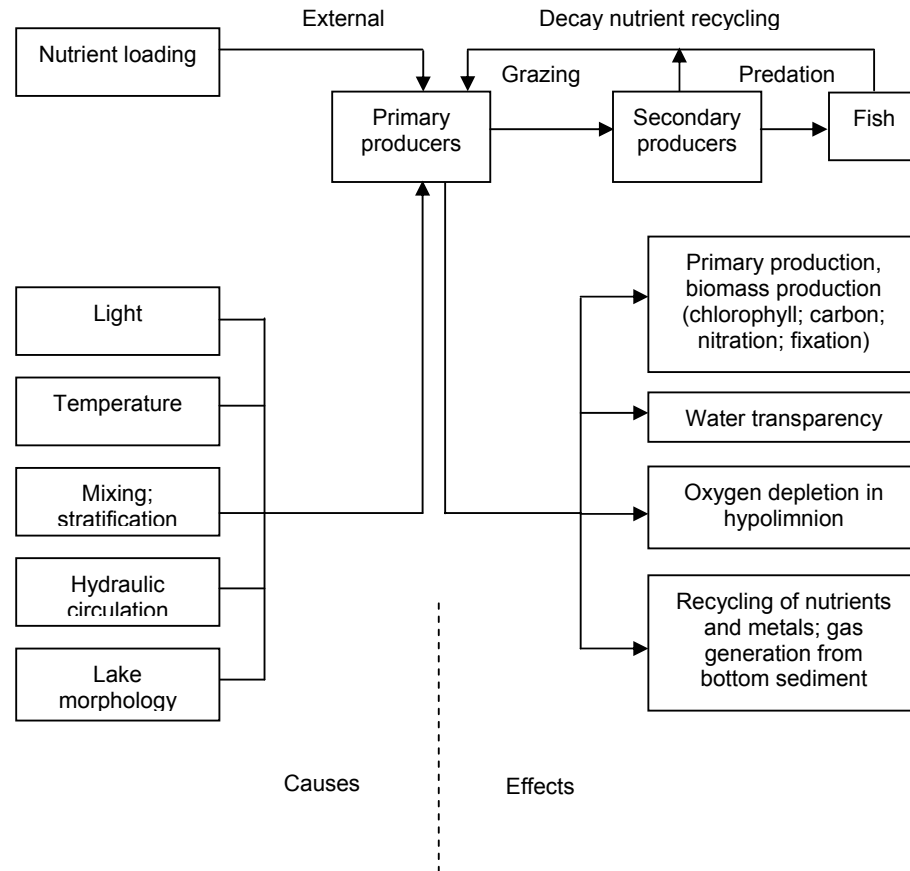


Figure 1. Causes and effects of eutrophication (UNESCO/WHO/UNEP, 1996)

Under most lake conditions, phosphorous and nitrogen are the most important nutrient factors causing the shift to a eutrophic state. If one of the elements is limiting and the other is available in excess of physiological needs, then theoretically, phosphorous and nitrogen can generate, 500 and 71 times their weight, respectively, in living algae (Wetzel, 2001). As phosphorus is usually the limiting nutrient for growth of aquatic plants, algal growth is generally decreased most effectively by reducing phosphorous inputs to below the level of losses within the water body (Wetzel, 2001; Drolc and Koncan, 2002). Another important management consideration is that accelerated eutrophication of aquatic systems is associated with surface rather than subsurface inputs of phosphorous (Merrington *et al.*, 2002).

Direct and indirect biological changes occur as a result of the mobilization of nutrients. Direct changes are induced by the nutrient influx; indirect effects are

¹ Water becomes anoxic due to temperature stratification and the decomposition of organic matter by bacteria.

largely due to decreased oxygen concentrations (Table 1). Eutrophication can result in marked variations in dissolved oxygen and pH in water bodies during the day and night. In slow-flowing or impounded water bodies, the effects of eutrophication can cause deoxygenation of the sediments and possible remobilization of nutrients and toxic trace elements. The resulting changes in water quality can be a major stress to aquatic life, particularly due to the release (at high pH) of gaseous ammonia, which is highly toxic (Chapman, 1996).

Table 1. Impacts of eutrophication

Direct Impacts	Indirect Impacts
<ul style="list-style-type: none"> ▪ Increase in production and biomass of phytoplankton, attached algae and macrophytes ▪ Production of toxins by certain algae 	<ul style="list-style-type: none"> ▪ Shift in habitat characteristics ▪ Replacement of desirable fish with less desirable species ▪ Increased operating expenses of public water supplies, including taste and odor problems ▪ Deoxygenation of water, especially after collapse of algal blooms ▪ Fish kills ▪ Infilling and clogging of irrigation canals ▪ Loss of recreational use of water ▪ Impediments to navigation ▪ Economic losses

(Harper, 1992; FAO, 1996)

1.2 Measuring Eutrophication

There are several indices for determining the extent of eutrophication of water bodies. These indices represent nutrient concentrations (nitrate, nitrite, total phosphorous) and biomass production (transparency and chlorophyll), as shown in Table 2.

Table 2. Nutrient levels, biomass and productivity at each trophic category

Trophic status	Mean total phosphorous (mg/m ³)	Mean total nitrogen (mg/m ³)	Annual mean chlorophyll (mg/m ³)	Chlorophyll maxima (mg/m ³)	Annual mean Secchi disc transparency (meters)	Minimum oxygen (% saturation)
Ultra-oligotrophic ↓	4.0	-	1.0	2.5	12.0	<90
Oligotrophic ↓	10.0	660	2.5	8.0	6.0	<80
Mesotrophic ↓	10-35	750	2.5-8	8-25	6-3	40-89
Eutrophic ↓	35-100	1875	8-25	25-75	3-1.5	40-0
Hypereutrophic	100.0	> 5,000	25.0	75.0	1.5	10-0

(UNESCO/WHO/UNEP, 1996; Wetzel, 2001)

1.3 Management and Control

The three approaches to controlling eutrophication, which are typically used in combination, are:

- Control of external nutrient sources;
- In-situ nutrient control, that is, the treatment of the water body to change its internal physical, chemical, or biological processes;
- In-situ control of algae.

Control of external nutrient sources

Diverting, treating, or limiting external nutrient inputs is the most important step to ensuring long-term prevention of eutrophication. There are several techniques for mitigating the effects of point sources (typically domestic and industrial wastewater and stormwater) and non-point sources (typically agricultural and urban runoff).

Nutrient diversion. Diversion of treated sewage or industrial wastewater involves the construction of interception lines to convey the wastewater away from the degraded water body to waters with greater assimilative capacity. The wastewater may already be collected in a sewer system and represent a point-source, which will require only a connecting pipe for diversion. On the other hand, where individual household septic tank drainfields or stormwater runoff constitute non-point sources, a collection system may be a necessary part of the diversion project. In either case, relatively large pipes are usually required to transport wastewater long distances and thus represent the greatest cost (Cooke *et al.*, 1992; Wetzel, 2001).

The costs involved in diversion of effluents vary greatly with the transport distance and the wastewater volumes involved. Costs of construction of diversions for lakes in the US have ranged between USD 8,000-550,000 per hectare or USD 350-1,350 per capita, and annual operation costs have ranged between USD 4-16 per capita (Cooke *et al.*, 1992).

Advanced wastewater treatment. Advanced wastewater treatment removes phosphorous, nitrogen, other nutrients, and ammonia from wastewater effluents. This can be achieved by a range of treatment techniques outlined in Table 3. The most commonly applied treatment involves the reduction of phosphorous concentrations by chemical precipitation. Typically, aluminum sulfate, calcium carbonate, or ferric chloride are added to an activated sludge tank following conventional primary and secondary treatment of sewage. The efficiency of this method ranges from 90 to 99 percent. Cost is dependent on volume of wastewater, chemicals for treatment, and sludge disposal. In the United States, the range has been between USD 6,000-13,000 per hectare or USD 600-1,100 per capita, with annual operation costs running typically at USD 77-115 per capita (Cooke *et al.*, 1992).

Table 3. Advanced wastewater treatment technologies for nutrient removal

Parameter	Treatment technologies
Nitrogen removal	<i>Biological</i> <ul style="list-style-type: none">▪ Anoxic/aerobic process▪ Step-feed anoxic/aerobic process▪ Intermittent aeration▪ Sequencing batch reactor▪ Post-anoxic denitrification with methanol addition
Phosphorous removal	<i>Chemical</i> <ul style="list-style-type: none">▪ Precipitation using metal salts and polymers <i>Biological</i> <ul style="list-style-type: none">▪ Anaerobic/aerobic only (A/O) process▪ Anaerobic/anoxic/aerobic (A²O) process▪ Phostrip process
Ammonia nitrogen removal	<i>Chemical</i> <ul style="list-style-type: none">▪ Air stripping▪ Chlorination▪ Ion exchange▪ Microfiltration▪ Reverse osmosis <i>Biological</i> <ul style="list-style-type: none">▪ Denitrification

Control of runoff. Compared to traditional point sources (where treatment is the most effective method), abatement of diffuse pollution focuses on land use, good agricultural practices, and surface runoff management (FAO, 1996; Drolc and Koncan, 2002). Physically limiting erosion is a first step to reducing nutrient runoff, turbidity, and sedimentation in water bodies. Table 4 lists several erosion control techniques. Their appropriateness to any given region varies with the economic development of the region, farmer capacity, and the acuteness of the problem (FAO, 1996).

Table 4. Erosion and surface runoff control techniques

Technique	Description
Conservation cover	Establish and maintain perennial vegetative cover to protect soil and water resources on land retired from agricultural production.
Conservation cropping	A sequence of crops designed to provide adequate organic residue for maintenance of soil tilth. This practice reduces erosion by increasing organic matter. It may also disrupt disease and insect and weed reproduction cycles, thereby reducing the need for pesticides. This may include grasses and legumes planted in rotation.
Conservation tillage	Also known as reduced tillage, this is a planting system that maintains at least 30 percent of the soil surface covered by residue after planting. Erosion is reduced by providing soil cover. Runoff is reduced and infiltration into groundwater is increased.
Contour farming	Ploughing, planting, and other management practices that are carried out along land contours, thereby reducing erosion and runoff.
Cover and green manure crop	A crop of close-growing grasses, legumes, or small grain grown primarily for seasonal protection and soil improvement. Usually it is grown for one year or less.
Critical area planting	Planting vegetation (such as trees, shrubs, vines, grasses, or legumes) on highly erodible or eroding areas.
Crop residue use	Using plant residues to protect cultivated fields during critical erosion periods.
Delayed seedbed preparation	Any cropping system in which all crop residue is maintained on the soil surface until shortly before the succeeding crop is planted. This reduces the period during which the soil is susceptible to erosion.
Field borders and filter strips	A strip of perennial herbaceous vegetation along the edge of fields. This slows runoff and traps coarser sediment. This is generally not effective for fine sediment and associated pollutants.
Grassed waterways	A natural or constructed channel that is vegetated, graded, and shaped so as to inhibit channel erosion. The vegetation also serves to trap sediment that is washed in from adjacent fields.
Strip cropping	Growing crops in a systematic arrangement of strips or bands across the general slope (not on the contour) to reduce water erosion. Crops are arranged so that a strip of grass or close-growing crop is alternated with a clean-tilled crop or fallow.
Terracing	Terraces are constructed in earthen embankments that retard runoff and reduce erosion by breaking the slope into numerous flat surfaces. Separating slopes are protected with permanent vegetation or are constructed from stone. Terracing is carried out on very steep slopes, and on long gentle slopes where terraces are very broad.

(FAO, 1996)

Phosphorous runoff can be reduced by addressing the sources and transfer mechanisms of the nutrient, as summarized in Figure 2. Source management – for example, better farm-scale nutrient budgeting and balancing of phosphorous inputs for livestock and crop production – has the dual benefits of financial savings and environmental protection. Erosion control measures (such as those shown in Table 4), selection of alternative crops, rotation tillage, and plant stubble management all can limit nutrient transfer (Merrington *et al.*, 2002). Other treatment techniques, although not well-documented, include wet and dry detention basins, predetention basins with phosphorous removal, and diversion of runoff to wetlands (Cooke *et al.* 1992; LWA, 2002).

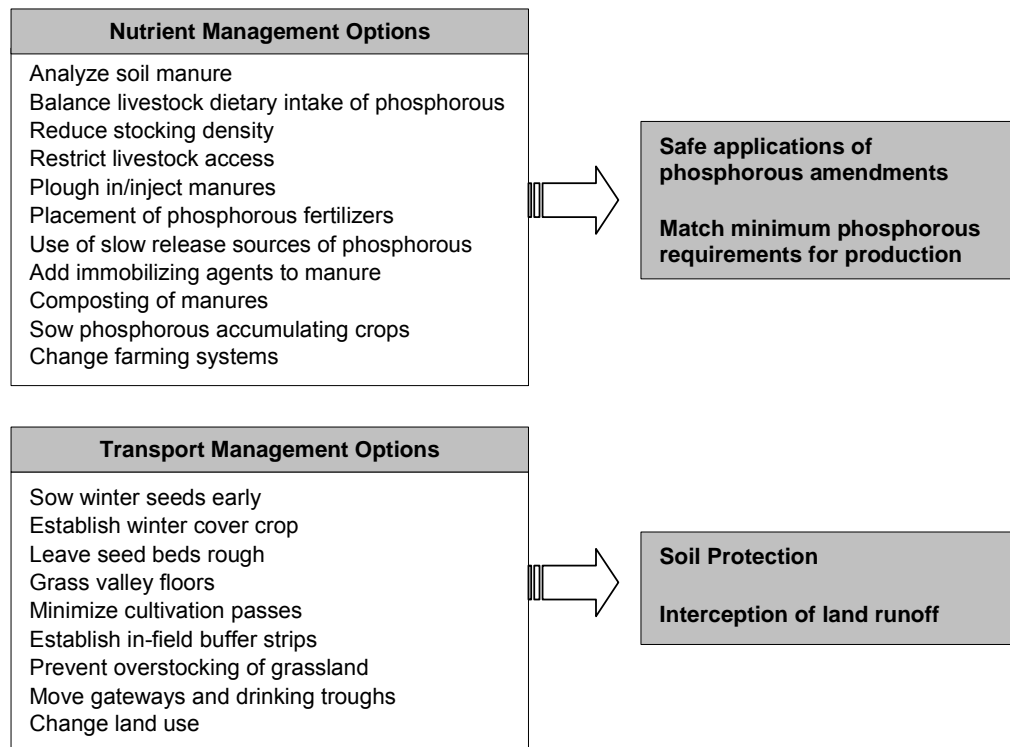


Figure 2. Nutrient and transport management options for the control of phosphorous loss from non-point sources (modified from Merrington *et al.*, 2002)

Control of nitrogen is similar to control of phosphorous. Techniques include:

- Rational nitrogen application based on plant needs and the amount nitrogen in the soil;
- Maintenance of vegetation cover to absorb mineralized nitrogen and minimize leaching during periods of rain;
- Crop rotation management through planting of “green manure” crops and delaying the ploughing of straw, roots, and leaves into the soil;
- Rational or precision irrigation; and
- Use of other cultivation techniques to optimize crop production, such as weed, pest and disease control, soil liming, and use of balanced mineral fertilizers (FAO, 1996).

In-situ nutrient control

In-situ treatments that alter one or more internal chemical, physical, and biological processes in a water body are sometimes required because of extensive shallow areas or internal recycling of toxics or nutrients, which allow continued production of algae and other biomass. Table 5 shows common methods for in-situ nutrient control.

Table 5. Common methods for nutrient control

Method	Remarks
Hypolimnetic withdrawal	<ul style="list-style-type: none"> Removal of nutrient-enriched hypolimnetic water by large-scale siphoning, pumping, or deepwater discharge. Applicable to stratified lakes and small reservoirs. Requires the installation of a pipe along the lake bottom to act as a siphon that transports water from shallow areas towards the deepest point in the lake. If designed and regulated carefully, hypolimnetic removal can take place without thermal destratification.
Dilution and flushing	<ul style="list-style-type: none"> Removal of algae by reduction in concentrations of limiting nutrients (dilution) and increase in water exchange rate (flushing). Both dilution and flushing reduce the biomass of plankton algae. Dilution is feasible only where large quantities of low-nutrient water are available for transport to the affected lake. Method sometimes used in coordinated management with induced lake circulation, chemical precipitation, and biological manipulations.
Phosphorous inactivation	<ul style="list-style-type: none"> Addition of aluminum sulfate or sodium aluminate to the water for the removal of phosphorous through precipitation and the retardation of phosphorous release from lake sediments. An aluminum salt is added to the water column to form aluminum phosphate and a colloidal aluminum hydroxide floc to which certain phosphorous fractions are bound. The technique provides long term control of algal biomass by reducing the supply of essential nutrients rather than poisoning algal cells. Due to the varying alkalinity between lakes, the required dosages of applied salts are lake-specific. Phosphorous inactivation treatments of reservoirs is uncommon, largely because reservoirs are likely to experience high rates of nutrient and sediment loading, leading to a continuous increase in phosphorous loading and ultimately a decrease in the effectiveness of the treatment method.
Sediment oxidation	<ul style="list-style-type: none"> Functions by oxidizing the top layer (0.15 - 0.20 meters) of anaerobic lake sediment. The objective is to reduce internal phosphorous loading in lakes that have anaerobic sediment and high interstitial phosphorous concentrations. Chemical solutions are applied by direct injection into the sediment with a harrow device, usually 6 to 10 meters wide and equipped with flexible tubes that penetrate the sediment. The harrow is dragged along the lake bottom, disrupting the sediment and injecting the chemical solution into it. Costs vary by area of treatment, depth of lake, and acuteness of pollution.
Hypolimnetic aeration	<ul style="list-style-type: none"> Objectives are to increase the amounts of dissolved oxygen, provide an increased habitat and food supply for aquatic life, and establish aerobic conditions at the sediment-water interface. The technique counteracts anoxia and its associated problems by preventing the depletion of dissolved oxygen. Application by injection of air via air-lift systems. The rising bubbles drive the air-water mixture to the surface, exposes the water to the atmosphere, and then returns it back to the hypolimnion by an outer cylinder after venting the air bubbles. System is not efficient in shallow waters. Initial costs are high (USD 3/kilogram of pumped oxygen), but decrease with time.
Sediment removal (dredging)	<ul style="list-style-type: none"> Employed for the restoration of eutrophic lakes and canals. The technique simultaneously removes large quantities of stored nutrients, increases the mean depth of the basin, and removes toxic substances. Hydraulic dredgers are used for sediment removal in lakes. Costs range from USD 2.3-5.6 per cubic meter of removed sediments.

(Cooke *et al.*, 1996; Wetzel, 2001)

In situ control of algae

An immediate approach to mitigate eutrophication is to directly destroy algae, inhibit its growth, and/or remove it mechanically. Such techniques, however, offer only short-term solutions. These include mechanical removal, application of copper sulfate, application of barley straw, and flow management.

Mechanical removal. Algae can be removed from water bodies by scraping off the surface or by installing screens at water intake points. However, such techniques are not highly effective because algae exist at a microscopic level and have rapid growth rates (IARC, 1999).

Copper sulfate. Copper sulfate (CuSO_4) is an effective agent for the control of algal growth in canals and lakes. The application of this algicide into water results in the formation of cupric ions (Cu^{+2}), which inhibits photosynthesis, cell division, and nitrogen fixation in algae. These effects, however, are temporary and are associated with negative impacts on aquatic organisms and significant contamination of sediments.

The dose of copper required to control algal biomass is a function of the water characteristics. The chemistry and hydrological features of the treated waters determine the amount of copper that will be lost through precipitation, adsorption, washout, or dilution. Copper sulfate is applied by pulling burlap bags through the water, mechanical spreaders, sprayers, and helicopters.

The costs for using copper sulfate in algae management vary with the dose, frequency of reapplication, area to be treated, type of algal nuisance, and other factors specific to a give lake or canal. Typical cost ranges are listed in Table 6, based on 1990 dollar value.

Table 6. Typical cost ranges for CuSO_4 treatment

Treatment method	Costs (USD/ha)
CuSO_4 solution	30 - 316
CuSO_4 crystals	96 - 578
CuSO_4 – citric acid solution	62-700
Cu ethanolamine granular	346 – 1,432

Barley straw. A novel method for controlling algae is the use of barley straw, which when placed in water, decomposes and releases chemicals that inhibit the growth of algae (Figure 3).



Figure 3. Application of large bales and small sausage floats of barley straw

The use of straw was developed in the United Kingdom in the 1990s (IARC, 1999; Lembi, 2002). Barley straw works more effectively and for longer periods than wheat or other straws. The rotting of the barley straw is temperature dependent, taking 6-8 weeks for straw to become active when water temperatures are below 10°C, but only one to two weeks when the water is above 20°C. Once the straw is active, effectiveness then varies with the type of alga. Small unicellular species usually disappear after 6-8 weeks of application; larger filamentous algae (blanket weeds) survive for longer periods, or may not be affected at all if the straw is added too late in the growing season. The chemicals produced by the straw generally remain active for algae control for six to eight months. It is important that the straw is well aerated, as anaerobic decomposition can instead re-stimulate the growth of algae (IARC, 1999, Lembi, 2002).

The surface area of the water body determines the quantity of straw required. In stagnant waters, the dose rate starts at 50 grams per square meter, then is halved for a second application. Once the algal problem has been reduced, preventative applications are necessary at a rate of 10 grams per square meter. Turbid or muddy water requires larger amounts of straw not exceeding 500 grams per square meter, at which rate deoxygenation may occur. Table 7 describes methods of straw application, varying by the type of water body. When properly applied, straw has not been found to have any adverse effect on higher plants, invertebrates, or fish (IARC, 1999).

Table 7. Mode of straw application

Type of water body	Mode of straw application
Fast flowing rivers and streams	Straw applied in the form of 20 kilogram bales at 100 meter intervals; water flow prevents straw from becoming anaerobic.
Slow flowing rivers/ canals	Straw applied in a loose form, such as straw sausage, at 30 meter intervals to increase the diffusion of oxygen.
Garden ponds/ canals	Straw placed in net bag or tied into a bundle with string, attached to a flotation device, and anchored with stone or brick.
Lakes and reservoirs	Large sausage floats anchored at problem location.

Flow management. Flow management measures enhance the amount of oxygen in a water body and negate the conditions for algal growth (LWA, 2002). There are two typical methods:

- Increasing base flows through weir pools to prevent thermal stratification and increase turbidity thereby eliminating the light and temperature conditions that encourage blue-green algal growth, and
- Using pulsing flows that are of sufficient size and duration to cause mixing of the water from the surface to the bottom.

Oxygen levels can also be improved by allowing the growth of plants (e.g., phragmites) along the edge of the reservoir, or mechanically mixing the water.

2. CHARACTERIZATION AND CONTROL OF ALGAE PROLIFERATION IN CANAL 900

Canal 900 delivers water from Lake Qaraoun to a 1,750-hectare irrigation scheme in the southern part of the Bekaa valley. The canal is part of the South Bekaa Irrigation Project that will ultimately irrigate 21,500 hectares along the Litani River (Figure 4). The canal was rehabilitated in 2001 with refurbishment of 14 kilometers and the construction of an additional 4 kilometers. A pumping station at the foot of Qaraoun Dam supplies water to the canal. The overall pump system consists of four units that have a total capacity of 3 m³/second. The initial pump lifts water 65 meters to an altitude of 910 meters above mean sea level. Subsequent pumps move water along the canal to Kamed El Laouz at an elevation of 907 meters above mean seal level (Figure 5). By such measurements, the canal has a negligible slope of 0.2 percent.

The canal extends from the hill facing the Qaraoun Dam (station 0+000) to reach a closed end at the Kamed El Laouz area (station 18+000) (Figure 6). Along its way, the canal enters Qaraoun village at station 3+000 before crossing the Qaroun-Lala main road at station 4+400 (Figure 7). The canal then runs parallel to the Qaraoun-Joub Jannine main road between stations 4+400 and 14+000 (Figure 8), enters the village of Joub Jannine, and ends at Kamed El Laouz. There are plans, but currently no funds, to extend the canal further beyond that point.

Canal 900 is open over the majority of its length, although it enters several tunnels along its route to travel beneath residential areas (Figure 9). The canal has both rectangular and trapezoidal cross-sections (Figure 10) with a width ranging from 6 - 10 meters and a water depth of 1 - 2.1 meters. The canal has several supplementary structures, including access bridges, flow controlling gates, regulating reservoirs, and pumping stations (Figure 11).

Canal 900 currently serves three main areas: Qaraoun, Joub Jannine and Kamed El Laouz (Figure 12). In each area, a pump (station 4+700 at Qaraoun, station 9+800 at Joub Jannine, and station 17+200 at Kamed El Laouz) moves water from the canal into regulating reservoirs which then distribute water by gravity in pressured distribution networks that supply water on demand. In addition, there are several private water pumps along the right bank of the canal for domestic or irrigation use (Figure 13). Figure 14 summarizes the canal inflow/outflow pattern.

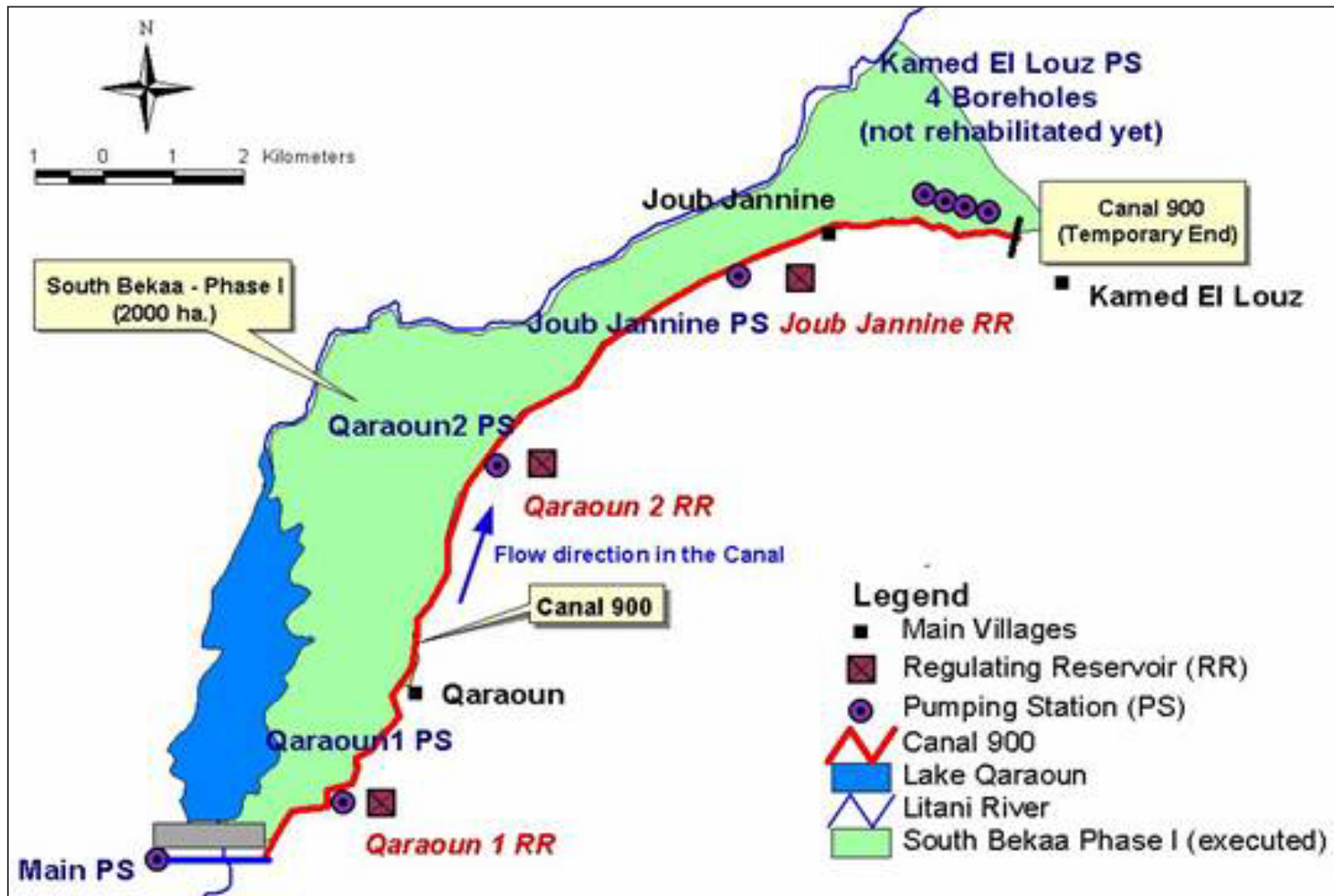


Figure 4. Layout map of South Bekaa Irrigation Scheme



Pumping station at the foot of the Qaraoun Dam



Water pipe ascending the hill



Water pipe discharging into Canal 900

Figure 5. Water supply to Canal 900 from Qaraoun Dam



Start of canal in Qaraoun area (station 0+000)



Closed end of canal in Kamed el Laouz area
(station 18+000)

Figure 6. Extremities of Canal 900



Entering Qaraoun village (station 3+000)



Crossing Qaraoun-Lala main road (station 4+400)

Figure 7. Canal crossing Qaraoun village



**Figure 8. Canal running parallel to Qaraoun-Joub Jannine main road
(between stations 4+400 and 14+000)**



Figure 9. Tunnel section of the canal in Joub Jannine area (station 16+200)



Rectangular



Trapezoidal

Figure 10. Various cross sections of Canal 900



Pumping station intake



Pumping station building



Access bridge



Flow controlling gate

Figure 11. Canal supplementary structures



Joub Jannine area



Kamed el Laouz area

Figure 12. Agricultural areas serviced by the canal



Figure 13. Small water pumps installed along the canal

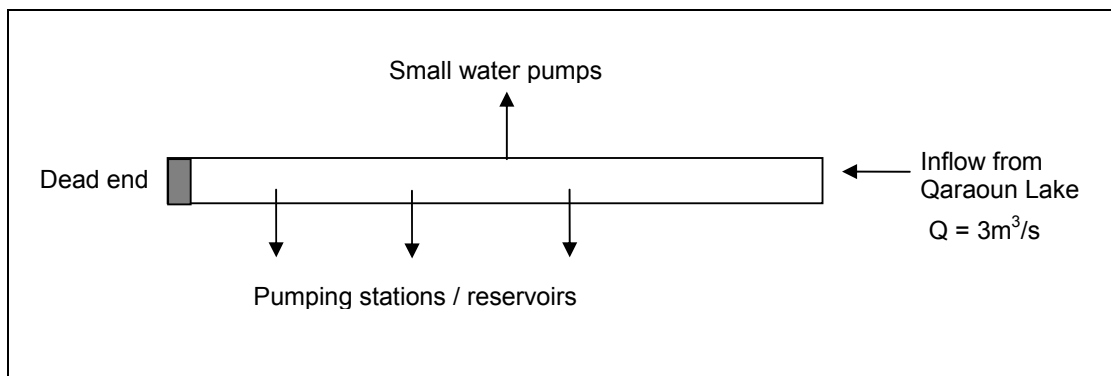


Figure 14. Schematic diagram of canal inflow/outflow pattern

2.1 Problem Description

If unabated, algae proliferation will impede water flow in Canal 900, block pumps, sluices, and filters (Figure 15), clog drippers, and possibly create a health hazard to humans, livestock, and wildlife by generating foul odors and attracting insects to neighboring areas. As discussed earlier, the problem is due to land and water management practices upstream leading to water quality degradation of the Litani River and excessive nutrient build up in Lake Qaraoun.



Figure 15. Clogging problems along the canal

2.2 Field Observations

Algae proliferation exists throughout the length of Canal 900 at varying intensities. Algae accumulation occurs first at station 1+400 where the canal changes from rectangular to a wider trapezoidal cross-section (Figure 16). Intermittent and moderate accumulations continue until the canal crosses the Qaroun-Lala main road (station 4+400). After that, between stations 4+500 and 17+700, the problem intensifies, particularly towards the closed end of the canal (Figure 17).

The canal suffers for low water velocity along the majority of its stretch due to the low slope (0.2 percent) and closed end, at which point it becomes a stagnant storage reservoir (Figure 18). The only exception is near pumping stations, which induce higher water velocities and inhibit algae accumulation (Figure 19). In response to algae proliferation, farmers have resorted to manual removal of algae using nets and screens (Figure 20). The field team observed no algae proliferation at Lake Qaraoun, the water source for Canal 900.

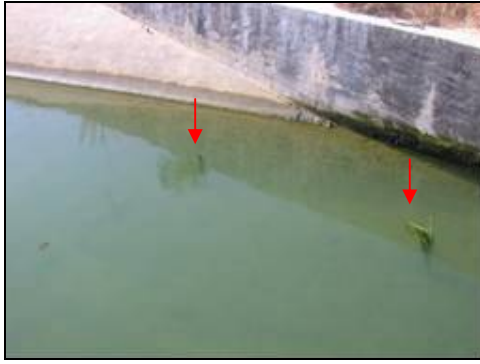


Figure 16. First observed algae accumulation (station 1+400)



**Figure 17. Large scale algae accumulations in the canal
(between station 4+500 and 17+700)**



Figure 18. Low water velocity causing stagnant water (station 17+700)



Figure 19. Higher water velocities at points of pumping



Figure 20. Currently applied algae removal practices

2.3 Sample Collection and Analysis

The field team collected water samples from Lake Qaraoun at varying depths along a line parallel to the canal intake and from the canal itself at various locations along its stretch, particularly where algae growth is well-developed. Appendix A lists the sampling locations and coordinates. The samples were analyzed for two categories of indicators:

- Indicators of the trophic status of the lake and canal: dissolved oxygen, total phosphorous, total nitrogen, and transparency;¹ and
- Indicators of the general pollution status of the lake and canal: pH, nitrates, sulfates, phosphates, chemical oxygen demand, total coliform, and fecal coliform.

Temperature, dissolved oxygen, total dissolved solids, pH, and transparency were measured in the field while the remaining parameters were analyzed at the laboratory. Sample collection, transport, holding and handling, and subsequent analysis were conducted in accord with *Standard Methods for the Examination of Water and Wastewater* as approved by the American Public Health Association, Water Environment Federation, and American Water Works Association. Appendix B lists the complete results of the analysis.

2.4 Results and Discussion

Analysis of samples shows the lake and canal to meet several standards of eutrophication (Table 8). Phosphorous in Lake Qaraoun is eight times higher than that typically termed hypereutrophic, while nitrogen levels are also high enough to make the lake hypereutrophic. The ratio of nitrogen to phosphorous is 7:1, indicating that phosphorous is the limiting nutrient for the control of algal growth. Dissolved oxygen in the lake is relatively low with a mean of 36.9 percent, corresponding to a eutrophic water body. Transparency in the lake is acceptable, with a mean of 4.1 meters and no biomass growth observed (Figure 21). In summary, while Lake Qaraoun has high nutrient levels, water depth and aeration prevent algal bloom.

In Canal 900, phosphorous and nitrogen levels are also high enough to be considered hypereutrophic, yet the concentration of phosphorous in the canal is half that found in the lake (379 milligrams per cubic meter as opposed to 810 milligrams per cubic meter). This is possible due to mobilization of phosphorous in the lake bottom sediments (due to low dissolved oxygen or perturbations during water intake), or, to the uptake of phosphorous by the algae growing in the canal. Phosphorous levels vary along the length of the canal due to the variable consumption rate by growing algae or external input from adjacent agricultural lands. Dissolved oxygen also varies (reaching a maximum of 90 percent saturation) due to the changing depth of the canal, water flow speed, and algae growth patterns. A Secchi disc transparency test was not applicable in the canal: owing to its shallow depth, the canal bottom is visible at all instances. In summary, the nutrient-rich water from Lake Qaraoun combined with the nature of the canal (low flow rate, gentle slope, closed end) are conducive to algae proliferation.

¹ Transparency of the water bodies was measured in the field using a Secchi disc.

Table 8. Characterization of the trophic status of the lake and canal

Parameter	Measured levels				Trophic status	
	Lake Qaraoun		Canal 900		Lake Qaraoun	Canal 900
	Mean	Range	Mean	Range		
Phosphorous (mg/m ³)	810	570-1,170	379	50-940	Hypereutrophic (> 100)	Hypereutrophic (> 100)
Nitrogen (mg/m ³)	5,000	< 5,000 – 9,000 ¹	5,200	< 5,000 – 12,000	Hypereutrophic > 5,000	Hypereutrophic > 5,000
Secchi disc transparency (m)	4.1	3.5-4.5	NA	NA	Mesotrophic (3-6)	NA
Oxygen (% sat)	36.9	15-59	55.3	15-90	Eutrophic (0-40)	Mesotrophic (40-89)



Qaraoun Lake



Canal 900

Figure 21. Transparency test using the Secchi disc apparatus

Water samples from the lake and canal were also analyzed in comparison to various national standards for different uses (Table 9). In general, the samples showed acceptable quality with moderate pollution, although this may be due to the unusually high amount of winter precipitation and flooding in 2002-2003. Four indicators, however, fell below standards:

- Nitrate, probably due to human and animal waste and fertilizer runoff, exceeds the recommended level for irrigation suitability.
- Dissolved oxygen falls below the Ministry of the Environment minimum recommended for aquatic life, indicating pollution of water with organic matter, particularly domestic and industrial wastewater.
- Total coliform, due to human and animal waste and soil runoff, exceed recommended standards in several location.
- Fecal coliform, also high due to human and animal waste, renders the canal unsuitable for drinking water.

Table 9. Water quality in the lake and canal

Parameter	Lake Qaraoun		Canal 900		Suitability for irrigation	MOE guidelines			
	Mean	Range	Mean	Range		Surface water for domestic use	Bathing water	Fresh water for aquatic life	Drinking water
DO (mg/l O ₂)	3.38	1.4-5.27	5.17	1.6-8.82	-	-	-	9	-
TDS (mg/L)	164	157-178	208	155-237	< 450	-	-	-	-
pH	7.1	6.6-7.7	7.3	6.8-8.1	-	6.5-8.5	6-9	6-9	6.5-8.5
Sulfate (mg/l SO ₄ ²⁻)	20	14-39	16	14-20	-	150	-	-	25
NO ₃ (mg/l)	9.0	5.3-11.1	9.8	6-14.1	< 5	25	-	-	25
Phosphate (mg/l PO ₄ ³⁻)	0.08	0.0-0.3	0.11	0.01-0.26	-	0.4	-	0.2	0.4
Fecal coliform (CFU/100 ml)	0	0	11	0-79	-	50	500	-	0
Total coliform (CFU/100 ml)	-	6 - >500	-	2- >500	-	20	100	-	0

2.5 Management and Control

There are three options for addressing eutrophication and algae in Lake Qaraoun and Canal 900:

- Reduction of external nutrient loadings into the Litani River and Lake Qaraoun;
- Treatment of Lake Qaraoun to reduce existing nutrient concentrations in its waters and sediments; and
- Direct inhibition of algal growth in Canal 900.

As discussed earlier, there are several techniques in relation to each of these options. Table 10 outlines these techniques and highlights their main advantages and limitations and Table 11 presents a comparative matrix to rank these techniques in terms of importance and appropriateness. The allocation of scores and weighting factors was based on reviewed literature, general experience and common knowledge. The ranking shows that the application of barley straw to the canal is the most appropriate first step. It is a relatively inexpensive step that community members could implement themselves; however, it is a short- to medium-term solution that does not address the real problem, namely high nutrient loadings in the Litani River and Lake Qaraoun. Thus, the second most favorable step is the promotion of better agricultural practices to limit runoff. Other viable steps are chemical inactivation of the phosphorous present in Lake Qaraoun and methods for improving the flow and recirculation of water in the canal. Flushing the lake itself with high-quality, low-nutrient water is not a viable option due to the cost and scarcity of such water.

**Table 10. Control techniques and their characteristics of concern
in the context of Canal 900**

Method	Remarks
1) Control of external nutrient sources	<ul style="list-style-type: none"> ▪ Long-term solution addressing the problem at its source
Nutrient diversion (intercepting lines)	<ul style="list-style-type: none"> ▪ Limited by the absence of domestic/industrial wastewater treatment plants ▪ Diverts pollutants to other locations within the watershed ▪ High capital cost
Advanced wastewater treatment	<ul style="list-style-type: none"> ▪ Limited by the absence of domestic/industrial wastewater treatment plants ▪ High capital cost
Good agricultural practices and land use	<ul style="list-style-type: none"> ▪ Requires training and capacity building programs for farmers and local stakeholders in the area ▪ Requires enactment and enforcement of agricultural and environmental policies and legislation
2) In-situ nutrient control	<ul style="list-style-type: none"> ▪ Essential if nutrient concentrations in the lake are high ▪ Does not control the source of nutrient loading
Hypolimnetic withdrawal	<ul style="list-style-type: none"> ▪ Requires advanced technical skills ▪ High capital and operation costs
Dilution and flushing	<ul style="list-style-type: none"> ▪ Requires large quantities of low-nutrient water ▪ High capital and operation costs
Phosphorous inactivation	<ul style="list-style-type: none"> ▪ Requires advanced technical skills
Sediment oxidation	<ul style="list-style-type: none"> ▪ Requires advanced technical skills
Hypolimnetic aeration	<ul style="list-style-type: none"> ▪ High capital and operation costs
Sediment removal (dredging)	<ul style="list-style-type: none"> ▪ Requires advanced technical skills
3) In-situ control of algae	<ul style="list-style-type: none"> ▪ Directly controls algal proliferation ▪ Temporary measure that does not reduce nutrient levels
Mechanical removal	<ul style="list-style-type: none"> ▪ Relatively low capital and operation costs ▪ Limited effectiveness at removal of algae ▪ Current method in use
Copper sulfate	<ul style="list-style-type: none"> ▪ Negative environmental impacts (sediment contamination)
Barley straw	<ul style="list-style-type: none"> ▪ Easy to apply by farmers ▪ No adverse effects if oxygenation is ensured
Flow management	<ul style="list-style-type: none"> ▪ Does not require advanced technical skills

Table 11. Comparative matrix for technique evaluation

Parameter	Weight	Score													
		Nutrient diversion		Advanced WWT		Good agro-practices		Mechanical removal		Copper sulfate		Barley straw		Flow management	
		R	W	R	W	R	W	R	W	R	W	R	W	R	W
Cost	2	1	2	1	2	2	4	2	4	2	4	3	6	2	4
Ease of application	3	1	3	1	3	2	6	3	9	3	9	3	9	2	6
Duration	2	3	6	3	6	3	6	1	2	1	2	2	4	1	2
Effectiveness	2	2	4	3	6	2	4	1	2	1	2	2	4	3	6
Environmental impact	2	2	4	3	6	3	6	3	6	1	2	3	6	3	6

Table 11 Comparative matrix for technique evaluation (continued)

Parameter	Weight	Score											
		Hypolimnetic withdrawal		Dilution / flushing		Phosphorous inactivation		Sediment oxidation		Hypolimnetic aeration		Sediment removal	
		R	W	R	W	R	W	R	W	R	W	R	W
Cost	2	1	2	1	2	2	4	1	2	1	2	1	2
Ease of application	3	1	3	1	3	2	6	1	3	1	3	1	3
Duration	2	2	4	2	4	2	4	2	4	2	4	2	4
Effectiveness	2	2	4	1	2	3	6	2	4	2	4	3	6
Environmental impact	2	2	4	2	4	2	4	3	6	3	6	1	2
Total			17		15		24		19		19		17

3. CONCLUSIONS AND RECOMMENDATIONS

Eutrophication and algae proliferation exist throughout Canal 900. Field surveys and water quality analysis of both the canal and Lake Qaraoun revealed the following:

- Lake Qaraoun, the water source for Canal 900, is hypereutrophic, with phosphorous concentrations exceeding 100 mg/m³.
- At many locations, Canal 900 is more like a stagnant reservoir, with a slope of 0.2 percent, a very low flow rate, and a closed end in Kamed El Laouz, all of which are conducive to algae proliferation.
- Algae proliferation varies along the canal and is lowest near pumping stations that increase water flow velocity.

This report recommends six measures to address these problems.

- **Apply barley straw to the canal.** This is a medium-term measure to inhibit algae growth that requires 6-8 weeks to become effective, depending on the extent of eutrophication. To be successful, this method should first be tested at a trial location in the canal, and farmers should receive guidance in timing, location, dose, and method of application.
- **Improve agricultural practices in the upper Litani River basin.** A long-term plan aimed at reducing nutrient loading in the Litani River basin (and consequently, the lake and canal) is crucial. It will require the government to communicate with stakeholders (by informing and advising farmers), regulate activities (through statutory prohibitions and legal sanctions), and incentivize behavior (through subsidies, capital grants, credit loans, and tax breaks and penalties).
- **Improve water recirculation in the canal.** This is a short-term measure consisting of installing water pumps at various stagnant locations along the canal, particularly its closed end at Kamed El Laouz, to continuously pump water back to upstream locations and improve aeration. For this method to work properly, the canal would first need to be drained and cleaned.
- **Treat water at the intake.** This is a short- to medium-term measure whereby water would be treated prior to entering the canal. This would require construction of a reservoir in which aluminum sulfate, calcium carbonate, or ferric chloride would be applied to induce chemical precipitation of phosphorous. Proper dosage and management of the precipitate requires technical training and oversight.
- **Treat water directly in Lake Qaraoun.** This is a medium- to long-term effort to treat the lake's waters and sediments, particularly aiming at phosphorous inactivation using aluminum sulfate or sodium aluminate. Success of this method requires data on nutrient budgets and the rate of nutrient recycling from the sediments.
- **Construct domestic wastewater treatment plants.** As a long-term measure aimed at reducing nutrient loading in the Litani River basin (and consequently, the lake and canal), this will require substantial financial outlays for the construction of plants using secondary and tertiary treatment methods to remove nitrogen and phosphorous from wastewater effluent.

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APPENDIX A. SAMPLING LOCATIONS

Table A-1. List of sampling locations along Canal 900

Sample number	Location coordinates		Distance from start point (m)	Comment
	North	East		
C1	33 32.770	035 42.041	0	Start of canal
C2	33 33.309	035 42.702	2,500	Open canal
C3	33 34.390	035 43.230	5,000	Open canal
C4	33 35.317	035 43.485	7,000	Open canal
C5	33 36.138	035 43.732	9,000	Open canal
C6	33 36.516	035 44.731	11,000	Open canal
C7	33 37.154	035 45.684	12,900	Open canal
C8	33 37.586	035 46.761		Into closed tunnel in Job Jannine
C9	33 37.771	035 47.544	16,510	Out of closed tunnel in Job Jannine
C10	33 37.643	035 48.500	17,760	End of last tunnel

Table A-2. List of sampling locations in Lake Qaraoun

Sample number	Location coordinates		Depth (m)
	North	East	
L1	33 32.993	035 41.087	6.5 (1/3 of depth from bottom)
L2	33 32.993	035 41.087	4 (1/2 of depth from bottom)
L3	33 32.956	035 41.219	23 (1/2 of depth from bottom)
L4	33 32.956	035 41.219	11.5 (1/2 of depth from bottom)
L5	33 32.925	035 41.415	34 (1/2 of depth from bottom)
L6	33 32.925	035 41.415	20 (1/2 of depth from bottom)
L7	33 32.898	035 41.578	25
L8	33 32.898	035 41.578	15
L9	33 32.927	035 41.699	11
L10	33 32.927	035 41.699	6

APPENDIX B. WATER QUALITY ANALYSIS

Table B-1 Analytical results for Canal 900

Parameter	Units	Samples									
		C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
Temperature	°C	19.8	22.2	20.5	23.2	23.6	23.9	29.3	26.0	27.0	27.4
pH	-	7.36	7.00	6.80	6.95	7.00	7.42	7.72	8.07	7.98	7.96
Total dissolved solids	mg/L	237	214	225	212	218	208	198	184	194	155
Dissolved Oxygen	ppm	1.60	4.39	3.30	3.86	5.30	6.84	UM ¹	UM	8.12	8.00
Dissolved Oxygen	% saturation	15	45	32	42	55	74	UM	UM	90	90
Transparency	m	TV ²	TV	TV	TV	TV	TV	TV	TV	TV	TV
Nitrates-Nitrogen	mg/L	3.2	3.0	2.1	2.0	2.0	2.0	2.2	2.0	1.4	2.1
Nitrates Total	mg/L	14.1	13.2	9.3	9.0	8.9	9.1	9.9	9.0	6.0	9.1
Total Nitrogen	mg/m ³	7,000	6,000	12,000	6,000	< 5,000	< 5,000	11,000	< 5,000	< 5,000	< 5,000
Phosphates	mg/L PO ₄ ³⁻	0.26	0.13	0.09	0.14	0.15	0.02	0.06	0.12	0.09	0.01
Total Phosphorous	mg/m ³ P	250	60	940	430	570	640	530	250	70	50
Sulfates	mg/L	16	15	14	15	16	15	14	20	15	17
Chemical oxygen demand	mg/L	7	3	<2	6	35	6	<2	3	3	11
Biological oxygen demand	mg/L	<2	<2	<2	3.8	3.9	5.4	<2	<2	<2	3.9
Fecal coliform	CFU/100 ml	79	4	1	0	1	0	0	0	0	0
Total coliform	CFU/100 ml	>500	20	55	47	32	29	2	61	17	213

¹ Unreliable measurement

² Total visibility

Table B-2 Analytical results for Lake Qaraoun

Parameter	Units	Samples									
		L1	L2	L3	L4	L5	L6	L7	L8	L9	L10
Temperature	°C	28.3	24.6	24.2	24.7	22.8	23.7	23.7	24.4	24.6	24.4
pH	-	7.75	7.42	7.25	7.3	7.0	6.7	6.9	6.6	6.9	7.3
Total dissolved solids	mg/L at 25°C	157	157	171	161	178	169	168	164	157	157
Secchi disc transparency	m	4.5	4.5	3.5	3.5	4.0	4.0	4.5	4.5	-	-
Dissolved Oxygen	ppm	5.22	5.27	2.63	3.9	1.49	2.40	2.35	2.06	3.92	4.57
Dissolved Oxygen	% saturation	59	55	27	43	15	26	25	23	43	53
Transparency	m	4.5	-	3.5	-	4.0	-	4.5	-	4.5	-
Nitrates-Nitrogen	mg/L NO ₃ ⁻ -N	2.6	2.2	2.3	2.1	2.0	2.0	1.2	2.0	1.9	2.2
Nitrates Total	mg/L	11.4	9.7	10.1	9.1	8.9	8.8	5.3	8.7	8.2	9.8
Total Nitrogen	mg/m ³	< 5,000	< 5,000	< 5,000	< 5,000	< 5,000	5,000	6,000	< 5,000	9,000	7,000
Phosphates	mg/L as PO ₄ ³⁻	0.05	0.00	0.02	0.01	0.11	0.02	0.30	0.15	0.10	0.06
Total Phosphorous	mg/m ³ P	570	630	690	780	1,160	890	910	760	890	830
Sulfates	mg/L SO ₄ ²⁻	39	22	16	15	19	20	16	14	16	18
Biological oxygen demand	mg/L	<2	<2	<2	<2	<2	<2	5.0	<2	3.4	<2
Chemical oxygen demand	mg/L	0.00	UR ¹	6	UR	UR	UR	30	0	8	3
Fecal coliform	CFU/100 ml	0	0	0	0	0	0	0	0	0	0
Total coliform	CFU/100 ml	200 ¹	150 ¹	8	205 ¹	55	6	>500	300	>500	258

¹ Under range detectable by analytical method

² Note that these colony counts are in 50 ml rather than 100 ml, as in the other samples